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Low-Energy Nuclear Science at LANSCE

Paul Koehler

**Group P-27
Los Alamos National Laboratory**

**Ohio University Nuclear Seminar
September 26, 2017**

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Outline

- Overview of the Los Alamos Neutron Science Center (LANSCE)
- Overview of neutron nuclear science at LANSCE

Weapons Neutron Research (WNR)

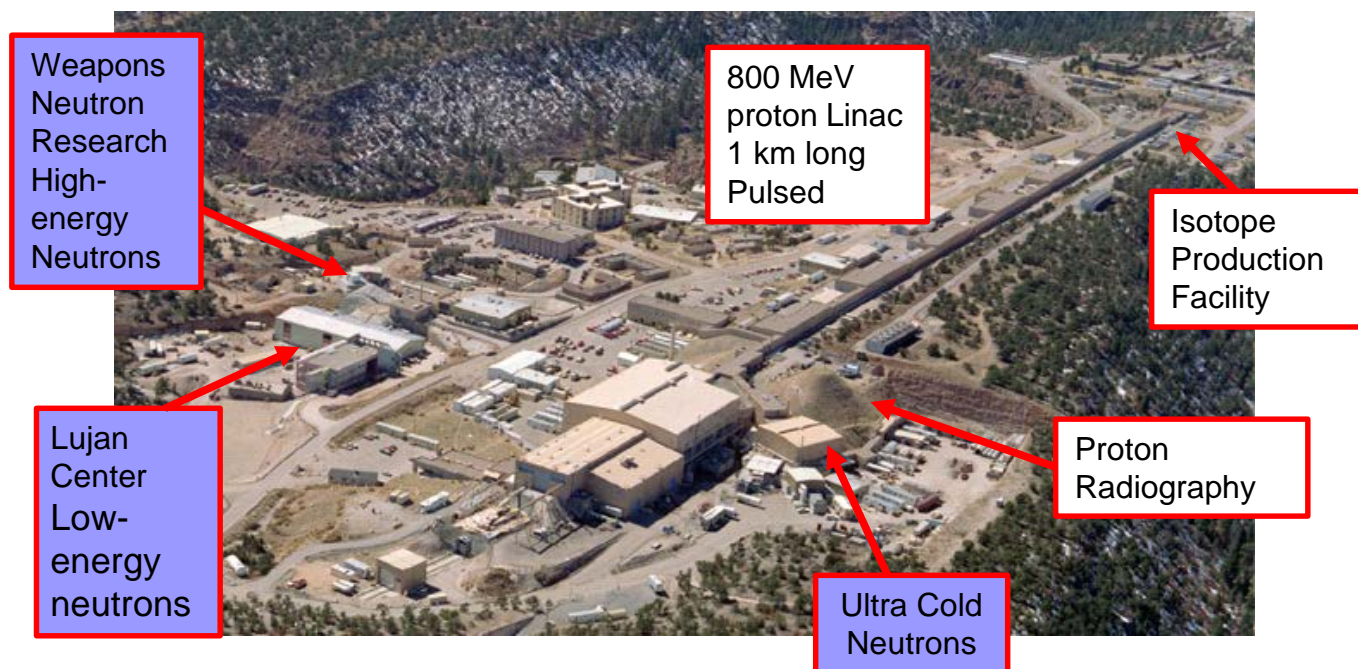
Manuel Lujan Neutron Science Center (MLNSC, or “Lujan Center”)

- A recent science result related to research at Ohio University
- Facility improvement scheduled for January 2020

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Los Alamos Neutron Science Center

P-27
operates and
does
research at 2
of the 3
neutron
facilities at
LANSCCE



Five major LANSCCE facilities operate simultaneously

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P-27 Scientific Staff

14 Staff Scientists

Aaron Couture
Matt Devlin
Nick Fotiadis
Charles Kelsey (DGL Ops)
Paul Koehler
Hye Young Lee
Michael Mocko
Shea Mosby
Ron Nelson
John O'Donnell
Eric Pitcher (GL)
John Ullmann
Steve Wender

Vacant (DGL Science)

7 Postdocs

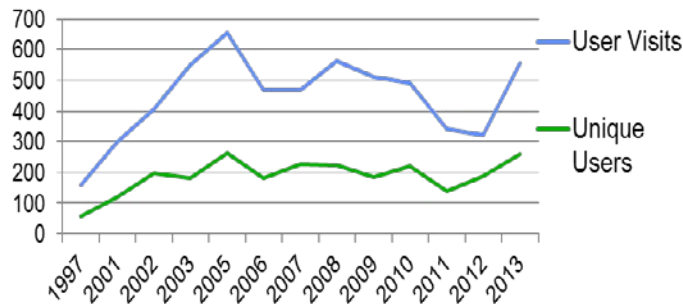
Jaime Gomez
Keegan Kelly
Alex Long
Chris Prokop
Jack Winkelbauer
Kyle Schmitt
Lukas Zavorka

Currently searching
for two new postdocs

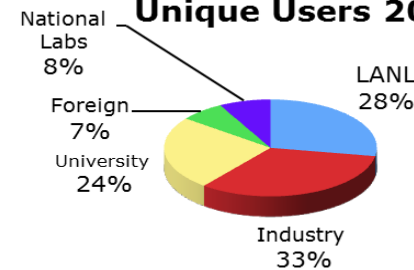
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Nuclear Science User Program statistics; WNR and Lujan Center

Nuclear Science Users



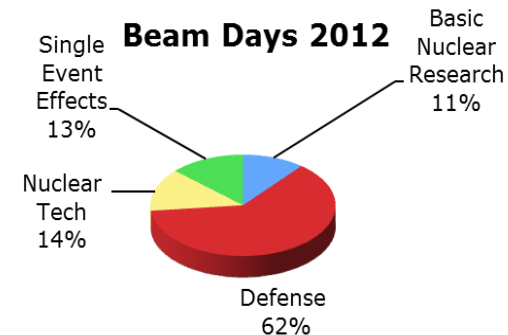
Unique Users 2012



Nuclear Science Proposals



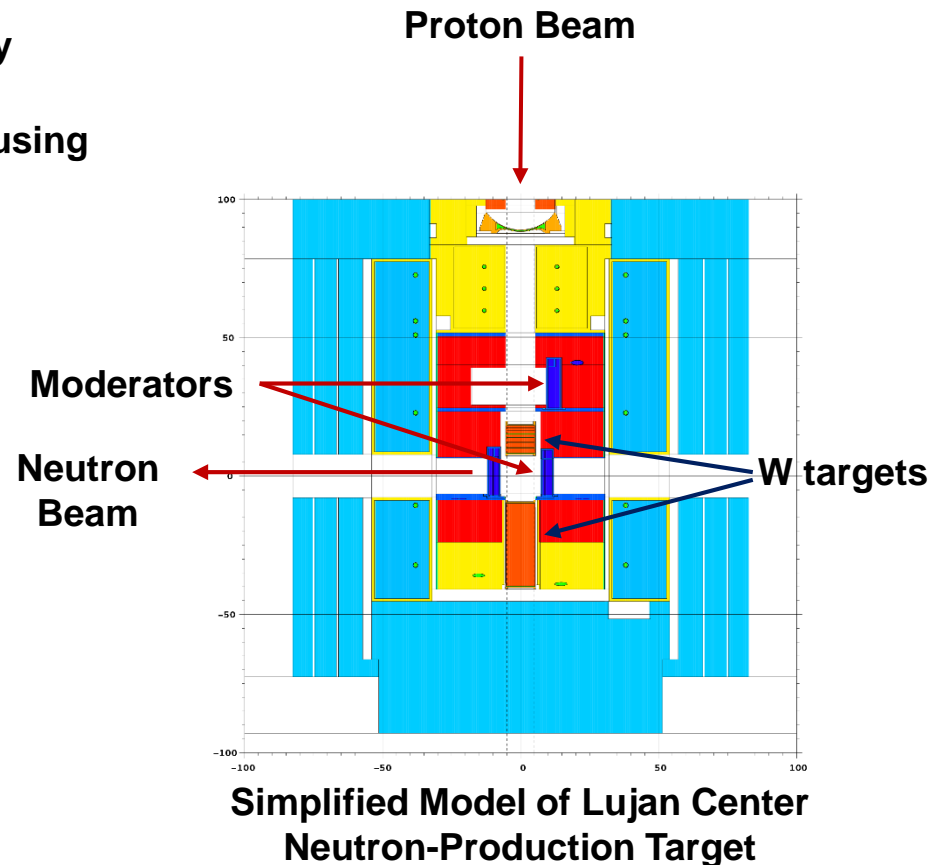
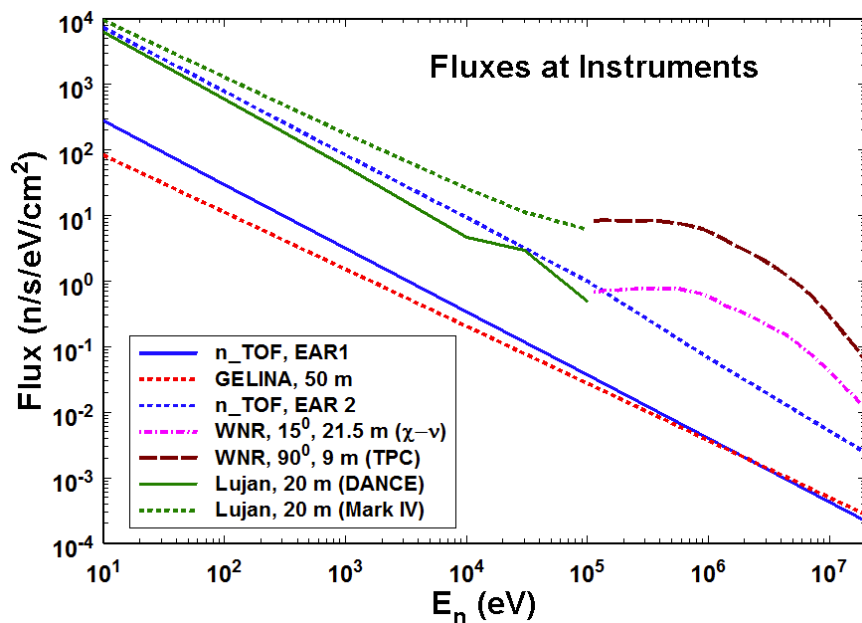
Beam Days 2012



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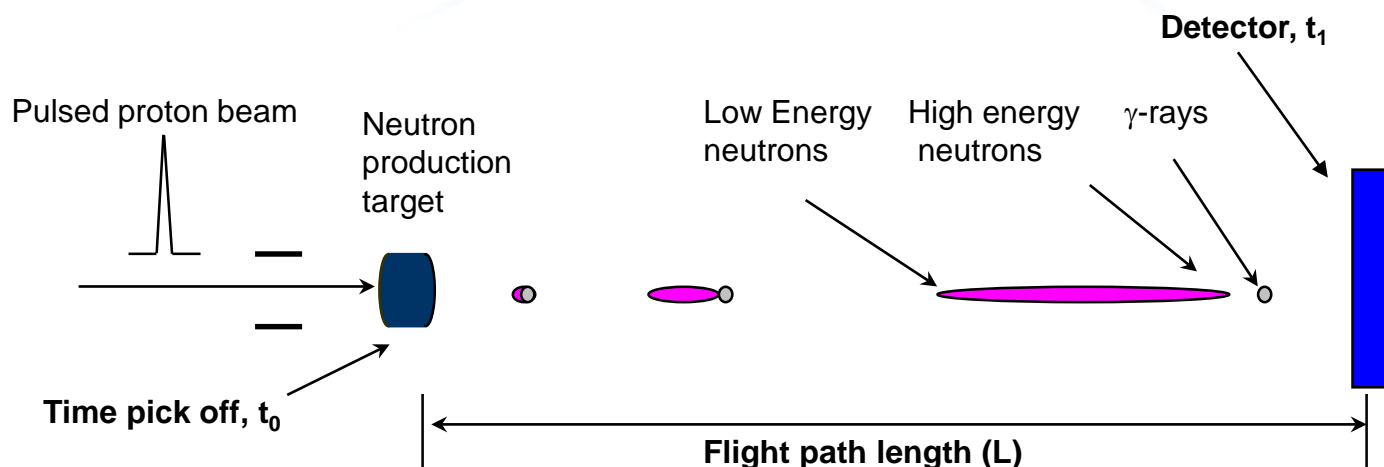
LANSCCE Neutrons Produced by Spallation

- 800 MeV protons strike a W target, producing a wide range of high-energy nucleons
- These nucleons “thermalize” and lower energy neutrons and nuclei are produced
- Neutron flux can be shifted to lower energies using H_2O or LH_2 moderators
- WNR unmoderated, $E_n > 500$ keV
- Lujan Center moderated, $E_n < 500$ keV

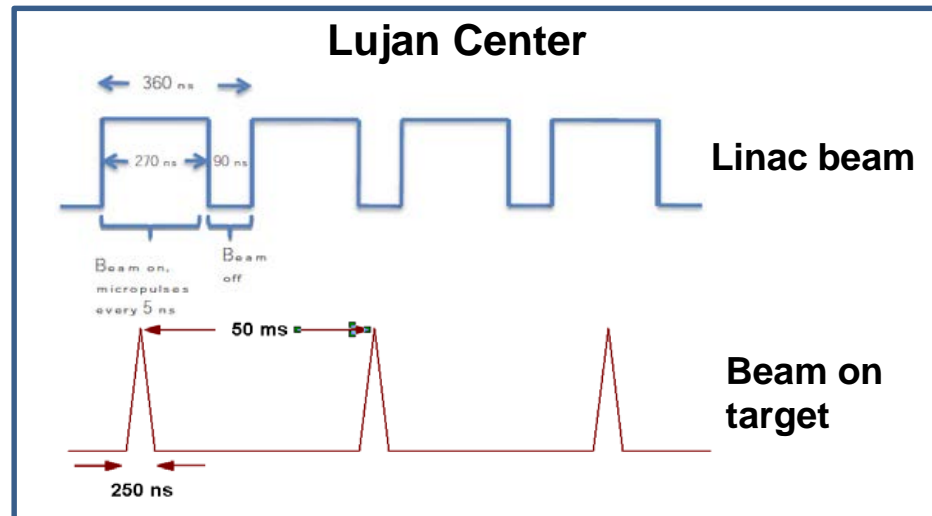
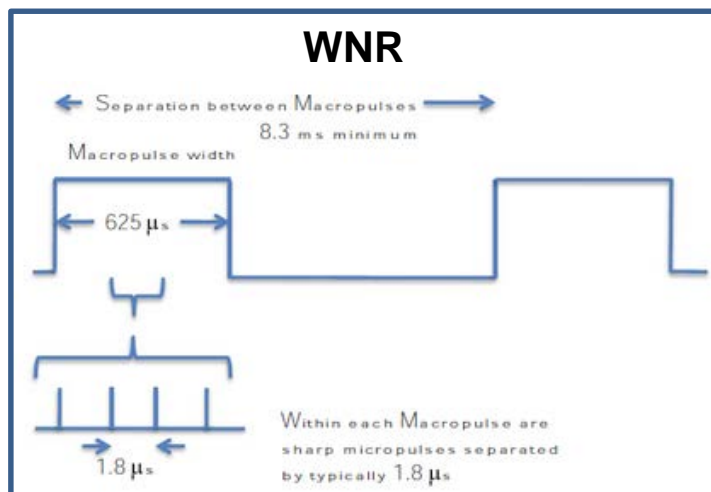


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WNR and the Lujan Center are White Neutron Sources; Neutron Energy Determined by Time-of-Flight



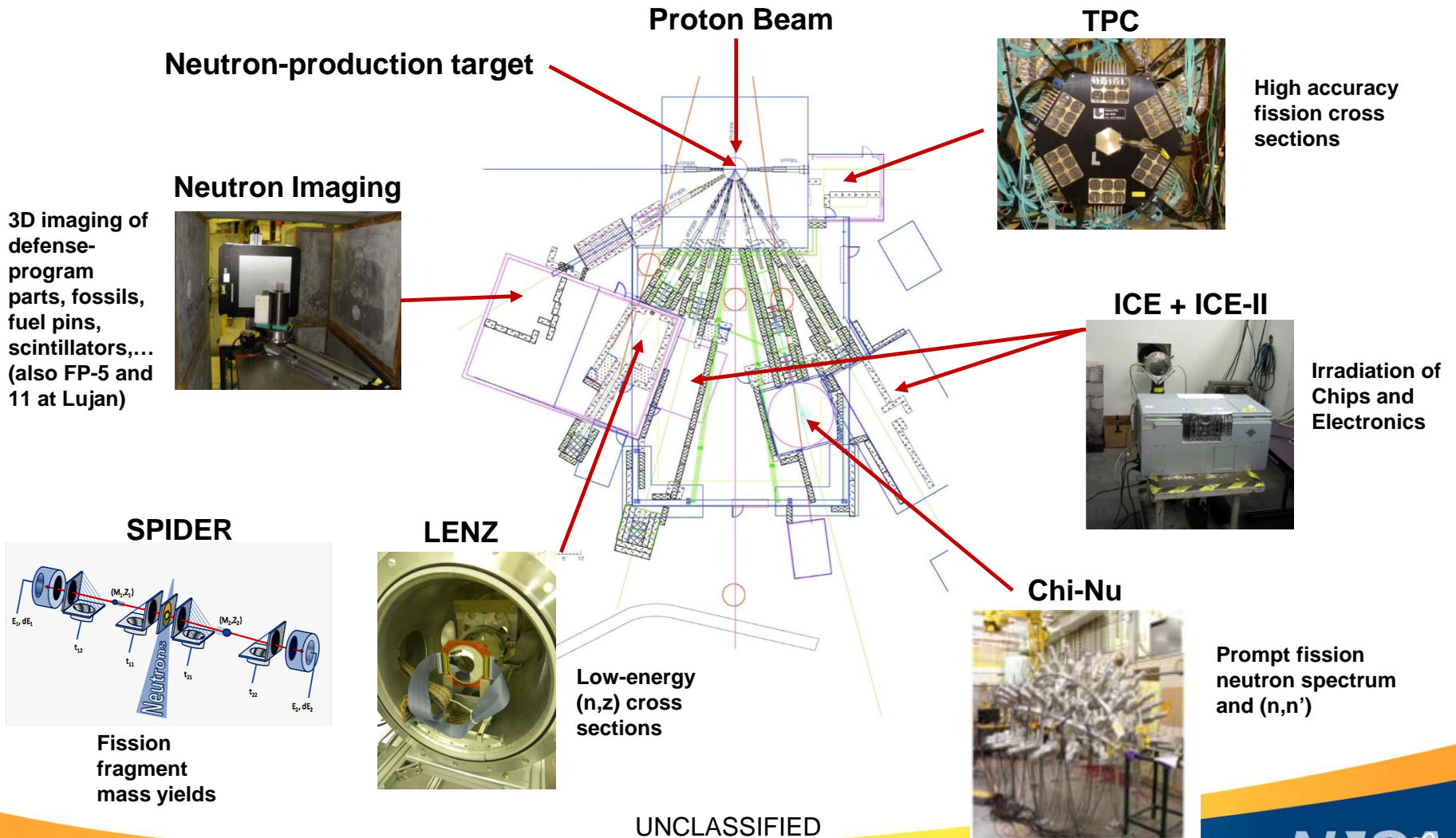
$$E_n = \left(\frac{72.3L}{t_1 - t_0} \right)^2$$



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Nuclear Science at the WNR

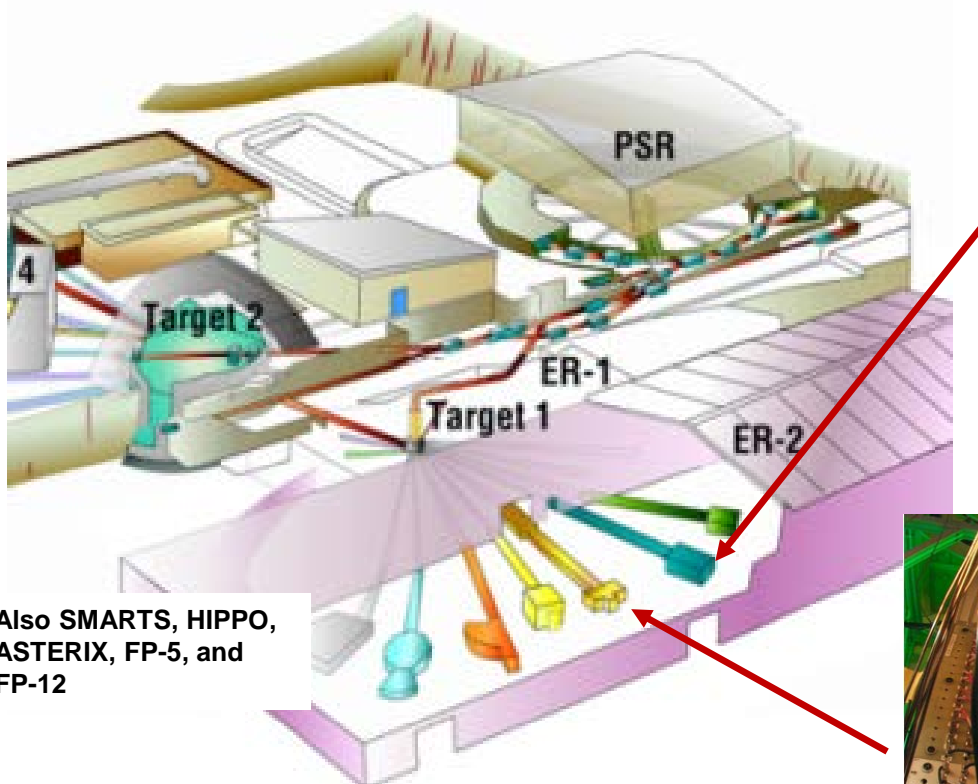
$E_n > 500 \text{ keV}$



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Nuclear Science at the Lujan Center

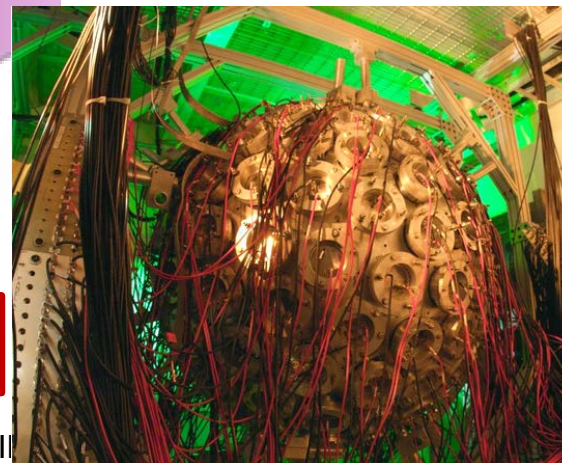
$E_n < 500 \text{ keV}$



Also SMARTS, HIPPO,
ASTERIX, FP-5, and
FP-12



DICER – Device
for Indirect
Capture
Experiments on
Radionuclides



DANCE –
Detector for
Advanced
Neutron Capture
Experiments

Tightly constraining (n,γ) rates on radionuclides is a very difficult challenge requiring multiple, coordinated experiments

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Chi-Nu Experiment at WNR

- **Goal:** Measure the prompt fission neutron spectra (PFNS) for ^{235}U and ^{239}Pu as functions of incident and outgoing neutron energies.

Affects reactivity

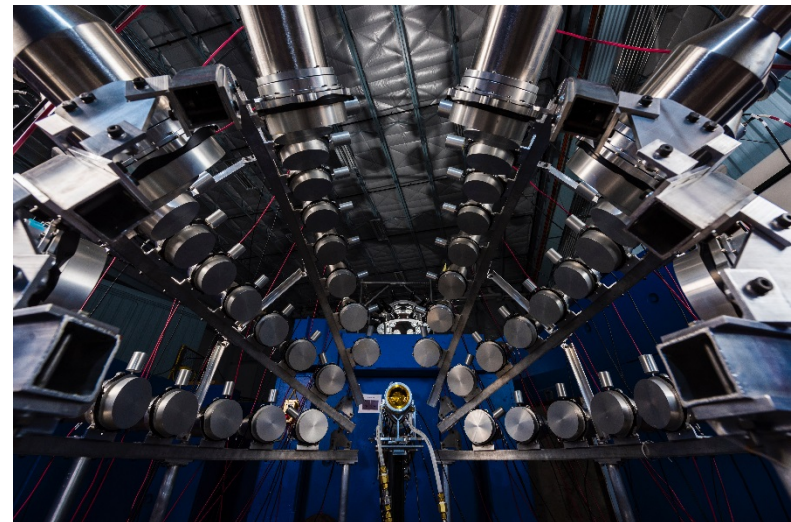
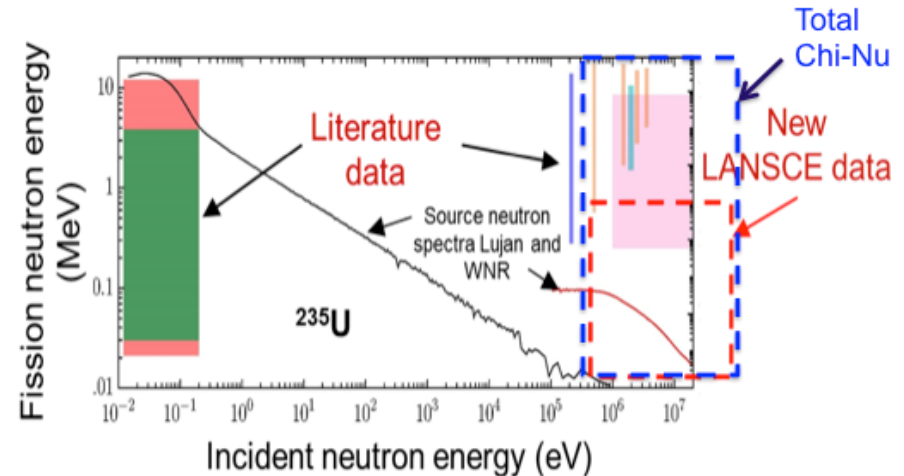
Past experiments had limited energy range and/or problems with systematic errors

- **Double TOF**

Incident E_n via TOF from neutron source to fission target (PPAC)

Outgoing E_n via TOF from PPAC to neutron detector (^6Li glass (22) and liquid scintillators (54))

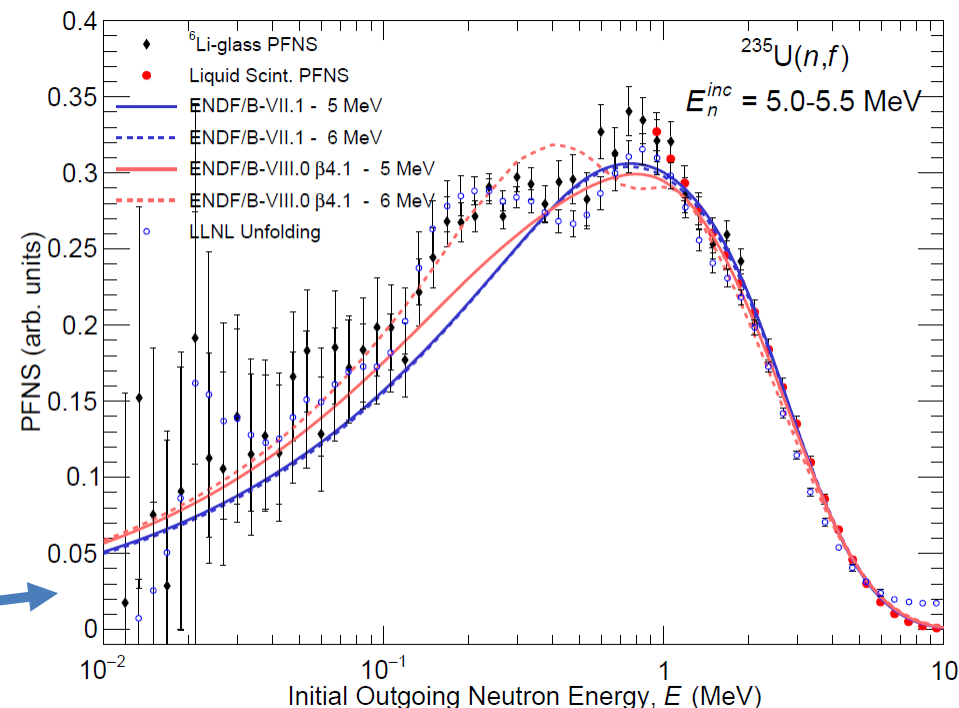
- **False floor to reduce room-return background**



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Chi-Nu Initial Results and Future Plans

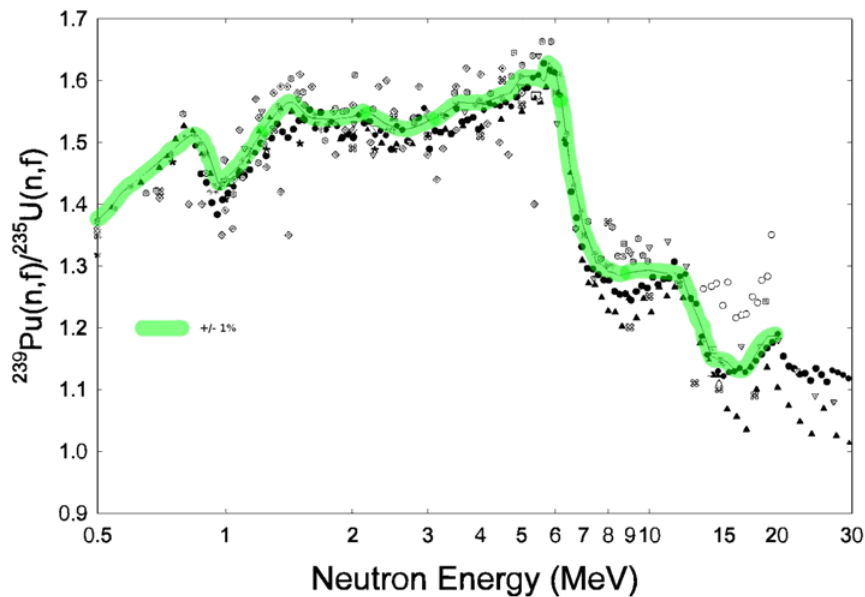
- Data taking completed for ^{235}U
- Extensive simulations to evaluate systematic errors
Revealed problems with previous experiments
- New method for high-precision background determination
- ^{239}Pu data taking $\frac{1}{2}$ finished
- ^{235}U data analysis nearing completion
Impacted ENDF/B-VIII evaluation
PFNS change at onset of second-chance fission
- Exploring use for (n,n') measurements
 $^{238}\text{U}(n,n')$ important for applications
- Contact: Matt Devlin



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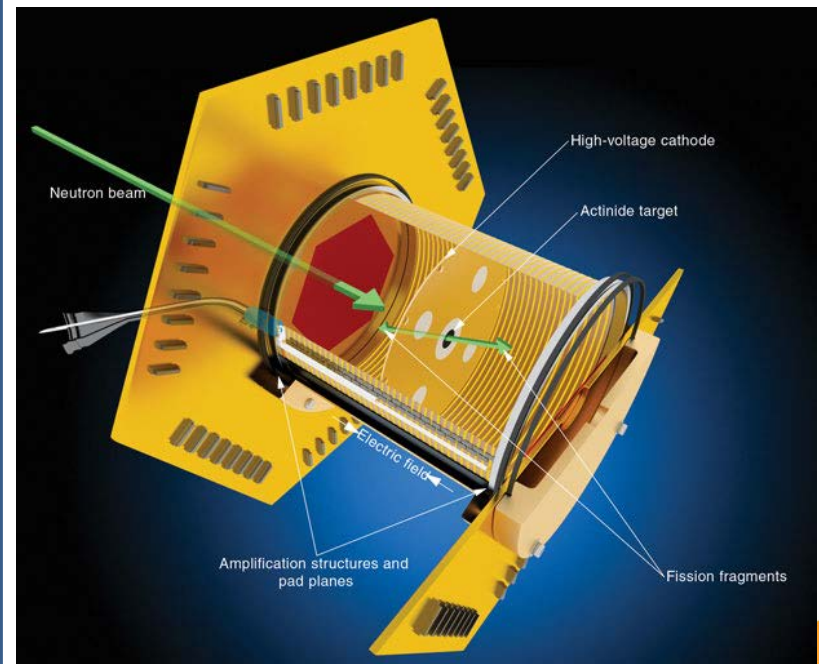
TPC: Time Projection Chamber (LLNL)

- Goal: High precision and accuracy ^{239}Pu and $^{235}\text{U}(n,f)$ cross sections
Resolve discrepancies in previous “precisely wrong” experiments



P. Staples, K. Morley, Nucl. Sci. Engl, 129, (1998)

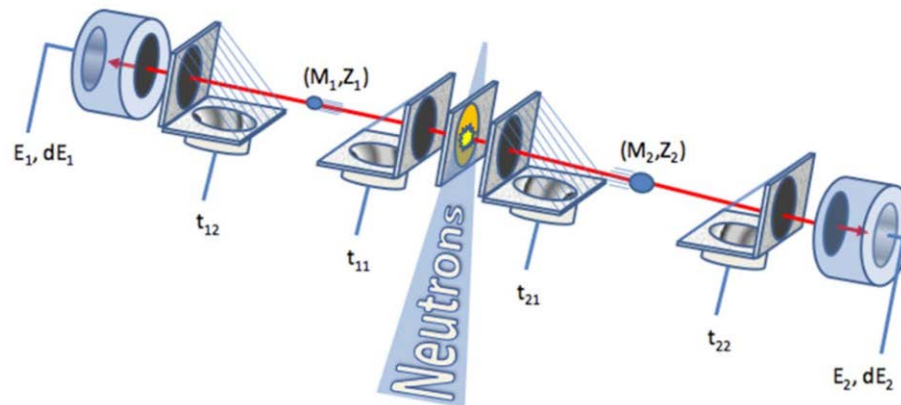
- Novel detector which should have different systematic uncertainties compared to previous approaches
Tracking fission fragments back to their origin should greatly reduce uncertainties due to target and beam non-uniformities



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SPIDER: SPectrometer for Ion DEtermination in fission Research

- Goal: Fission-fragment mass distribution with resolution of one mass unit
Important for radiochemical diagnostics
- Based on the 2E-2V Method
- Time-of-Flight
 - MCP-based time pick-offs with electrostatic mirrors.
 - 100ps (FWHM) resolution per detector
- Energy Measurement
 - Frisch-gridded Ionization Chamber
 - 0.5-1.0% resolution for fission fragments
 - Bragg-curve spectroscopy to determine atomic number Z
- Multiple detectors to increase efficiency
- Position resolution to reduce flight path uncertainty



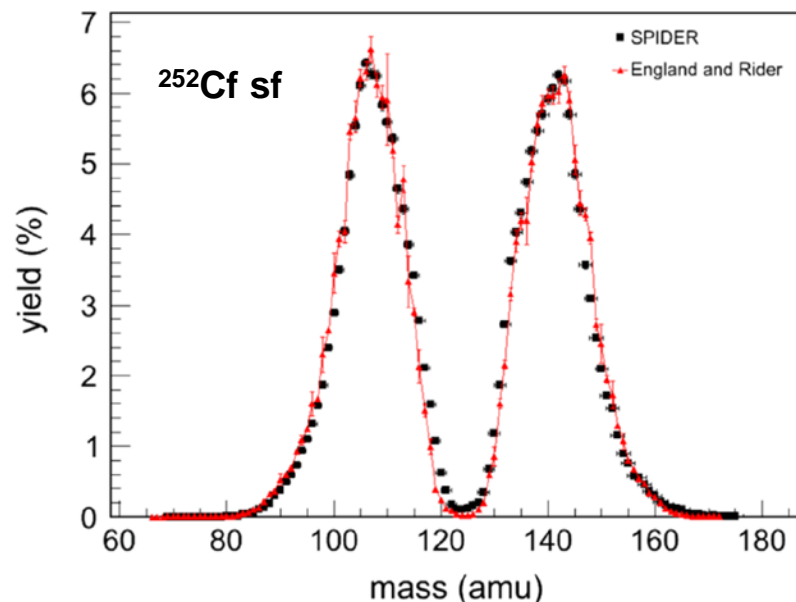
$$M = \frac{2Et^2}{l^2}$$

$$\frac{\delta M}{M} = \sqrt{\left(\frac{\delta E}{E}\right)^2 + \left(2 \frac{\delta t}{t}\right)^2 + \left(2 \frac{\delta l}{l}\right)^2}$$

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SPIDER Recent Results and Future Plans

- Completed measurements
 ^{252}Cf spontaneous fission
 ^{235}U thermal fission (FP-12)
- Mega SPIDER under construction
Multiple pairs of arms to increase efficiency
Future measurements planned at WNR
- Contacts: Shea Mosby and Jack Winkelbauer



Mega SPIDER Under Construction

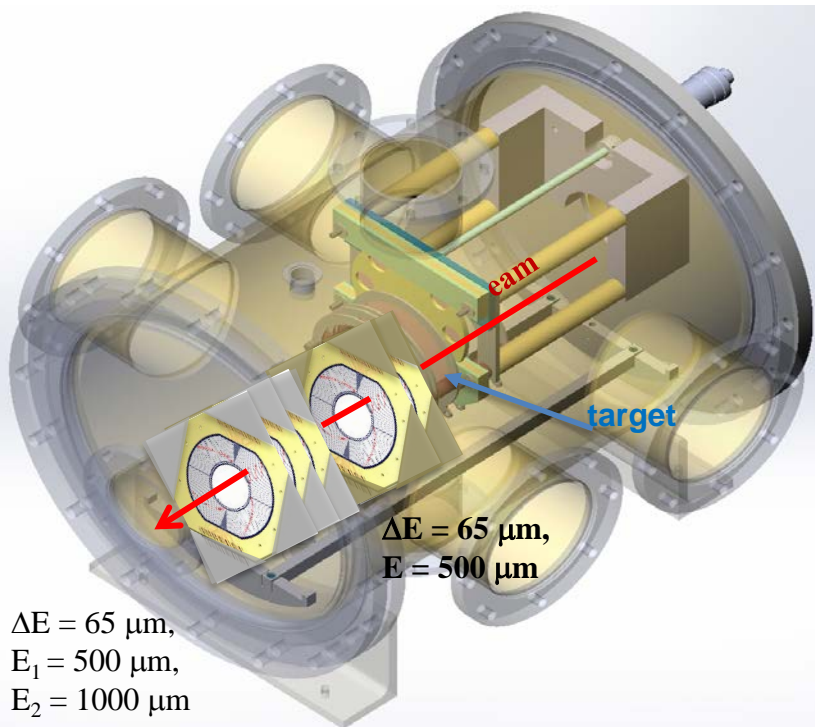
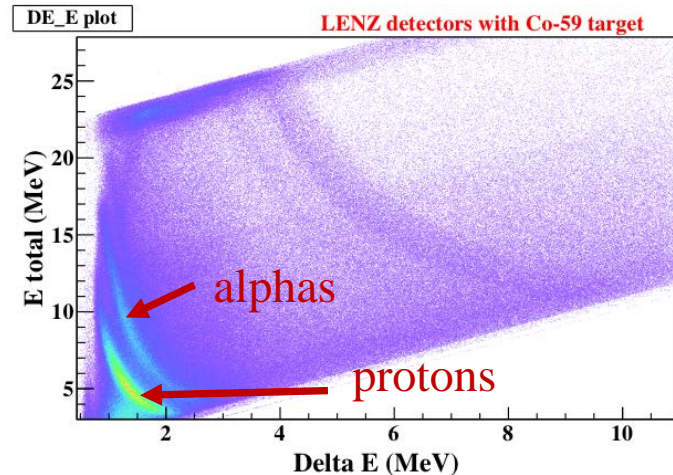
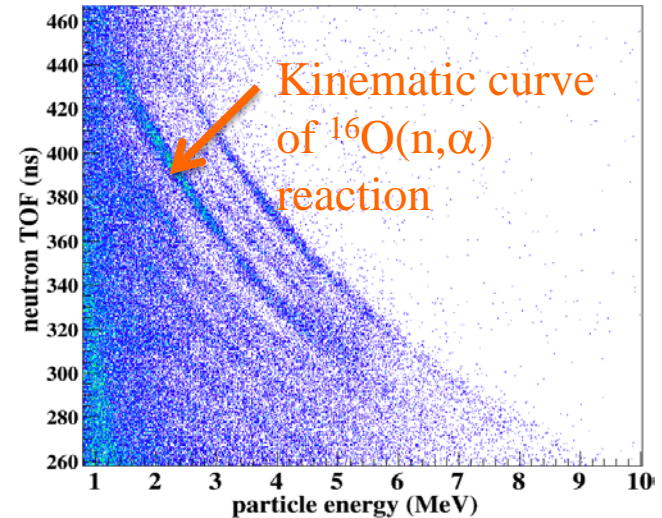


Meierbachtol et al., NIM A 788 (2015) 59-66

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LENZ: Low Energy (n,z)

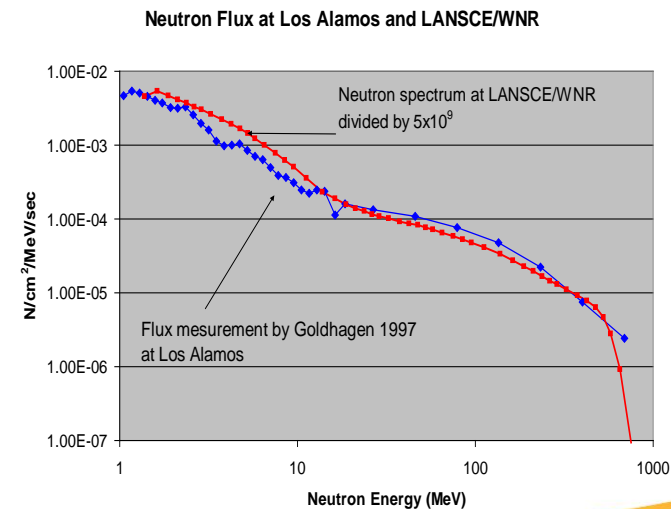
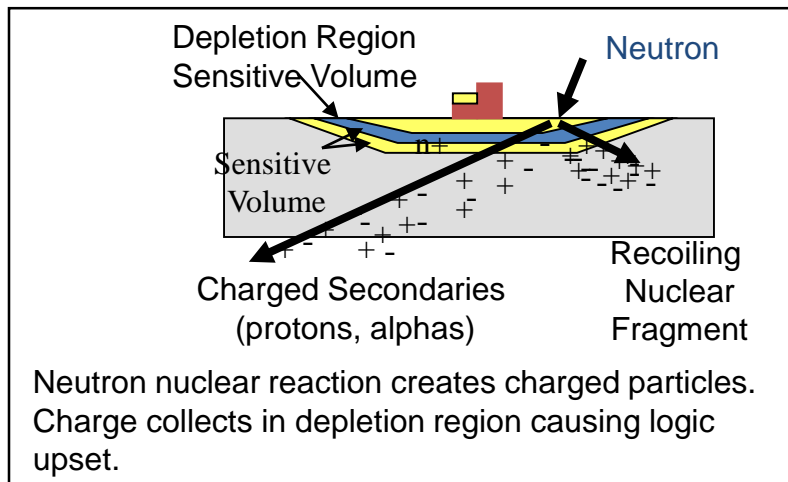
- Goal: Measure (n,p) and (n, α) cross sections for defense-program sponsors and nuclear astrophysics
LDRD ER project starts this October
- Large solid angle and low detection threshold
- Twin Frisch grid ionization chamber coupled with silicon strip detectors to measure angles and charged particles as a telescope
- Contact: Hye Young Lee



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ICE: Irradiation of Chips and Electronics

- Goal: Accelerated testing of failure rates of electronics due to neutrons
- Neutrons from cosmic rays interact in the device to produce charged particles
- Charged particles cause single-event upset (SEU) (bit flip)
- SEU failure rate equal to sum of all other failure rates
- WNR flux shape matches cosmic neutron flux
- **WNR flux is much larger which allows accelerated testing**
- No reliable model – accelerated testing is crucial

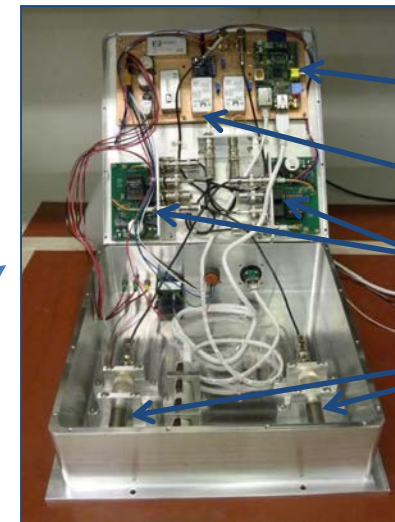


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ICE: Results and Future Plans

- Most ICE research is proprietary:
Avionics and semiconductor industries
Users pay for beam time
- ICE measurements explain 80% of ASCI Q-Machine failure rate
~3 fails/day
Traced to cache memory that was not error corrected
- New proton-irradiation facility being planned at LANSCE
Protons are the major threat in space
- Thermal neutron beam line at the Lujan Center being developed
Fuel and people in airplanes moderate neutrons, which generate α particles via $^{10}\text{B}(n,\alpha)$
Tinman detector developed by P-27 to measure thermal neutron flux in flight
- Contact: Steve Wender

ASCI Q-Machine at LANL



Raspberry Pi

Power supplies

Shaping pre-amps

Cylindrical ^3He ion chamber

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Neutron Imaging at WNR and Lujan Center

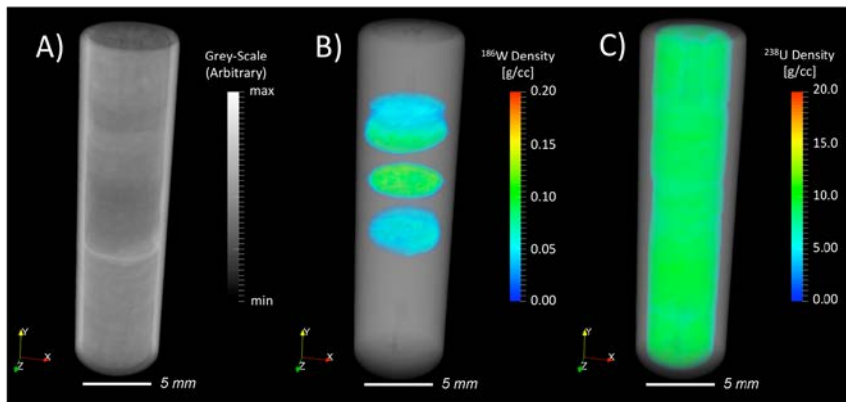
- Goal: Seeing inside thick, dense objects for defense-program sponsors and basic and applied science
Radiographs and tomographs
- Isotopic imaging by TOF gating on neutron resonances
- Phase-contrast imaging with cold and thermal neutron energies
- Contacts: Ron Nelson and Sven Vogel

High-energy neutron radiograph of a portion of the 75 million year old New Mexico “Bisti Beast” tyrannosauroid skull



T. Williamson, K. Schroeder, New Mexico Museum of Natural History and Science and UNM Albuquerque

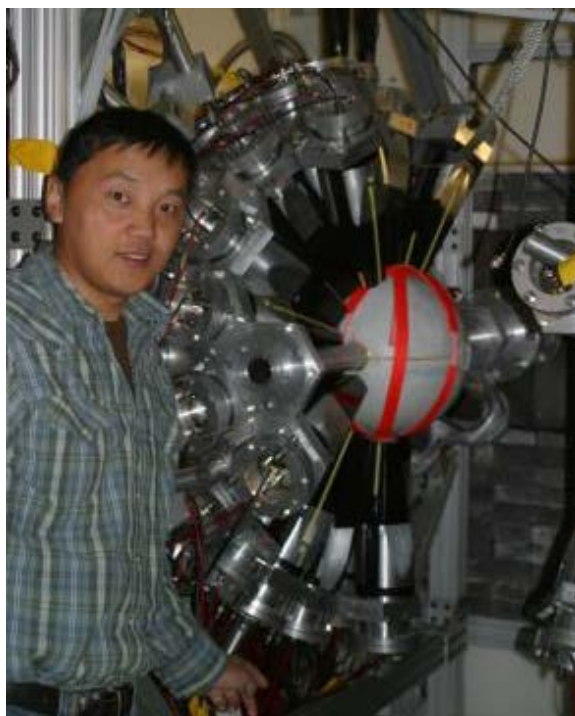
Separate ^{186}W and ^{238}U CT scans of mock fuel pellet



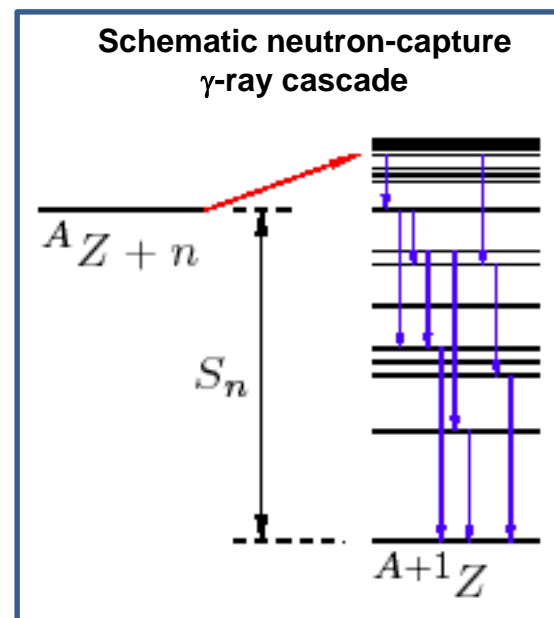
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DANCE: Detector For Advanced Neutron-Capture Experiments

- **Goal: Neutron-capture cross sections for very small (~1 mg) samples for defense-program sponsors and nuclear astrophysics**
- **Detailed γ -ray cascade data**
Excellent neutron resonance “spin meter”
Useful for testing and constraining photon-strength-function (PSF) and nuclear-level-density (NLD) models.
- **Simultaneous measurement of (n, γ) and (n,f)**
In coincidence with fission-tag detector (e.g. PPAC)
 γ -ray multiplicity helps to separate (n, γ) and (n,f)



Half of DANCE 4π array of 160 BaF_2 detectors

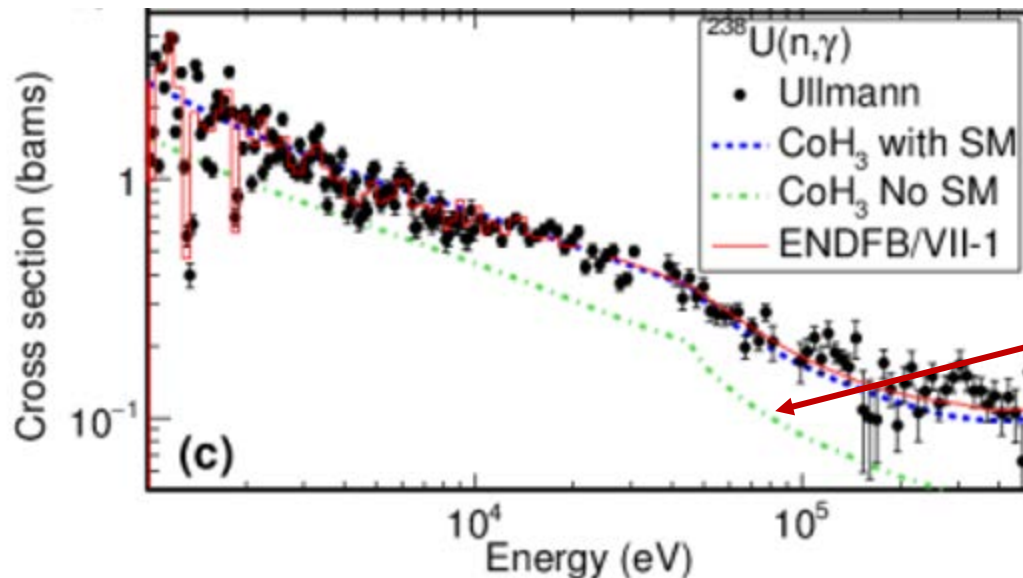


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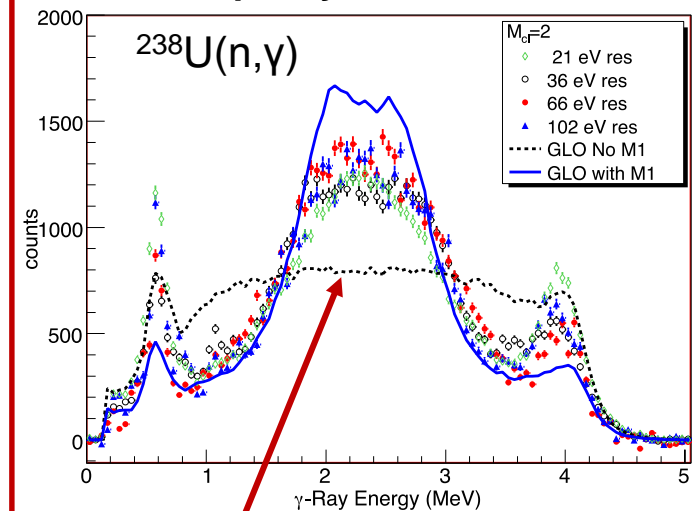
DANCE: Some Recent Results

- (n, γ) data on U isotopes demonstrate need for sizable M1 component to the PSF
Systematics important for applications involving nuclides in this mass region beyond the reach of experiments
- **Contacts: John Ullmann and Aaron Couture**

DANCE $^{238}\text{U}(n,\gamma)$ Data vs. Models



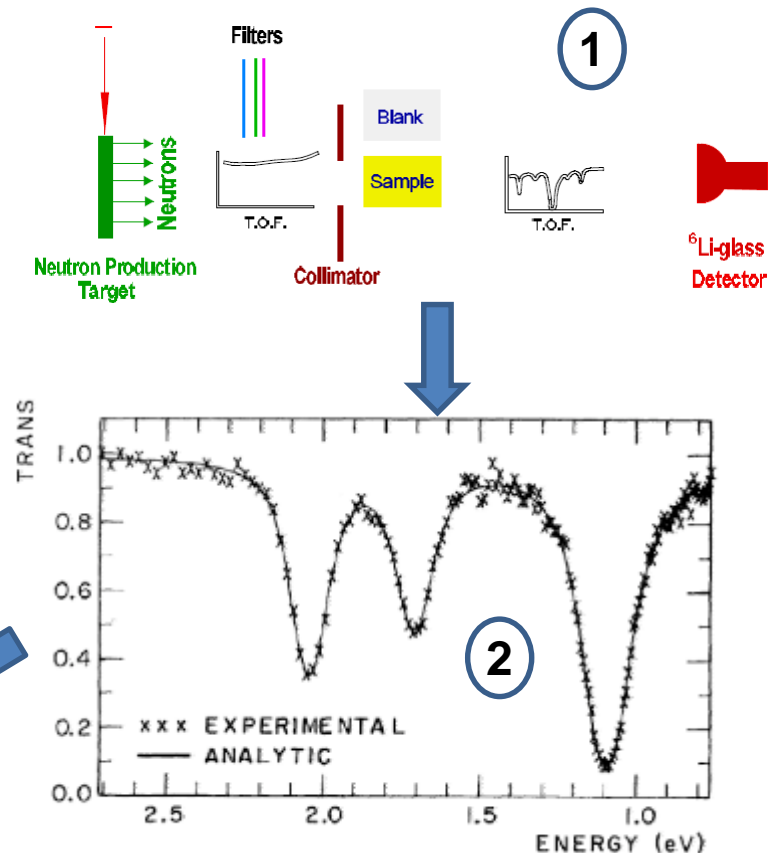
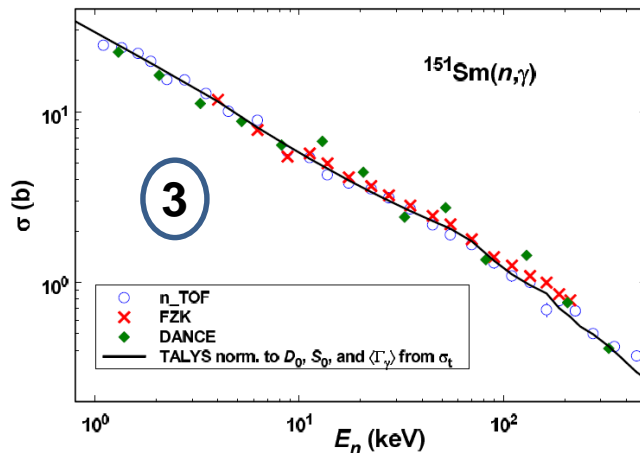
DANCE ^{238}U Resonance γ -ray Multiplicity Data vs. Models



Models without M1 Scissors-Mode Component in PSF Do Not Agree With DANCE Data

DICER: Device for Indirect Capture Experiments on Radionuclides

- Goal: Tightly constrain (n,γ) cross sections for nuclides beyond the reach of direct measurements for nuclear forensics, radchem diagnostics, and astrophysics
- Three-step approach
 1. Measure resonance transmission
 2. Extract average resonance parameters via R-matrix analysis
 3. Use nuclear statistical model calibrated with these average parameters to calculate $\sigma_{n,\gamma}$

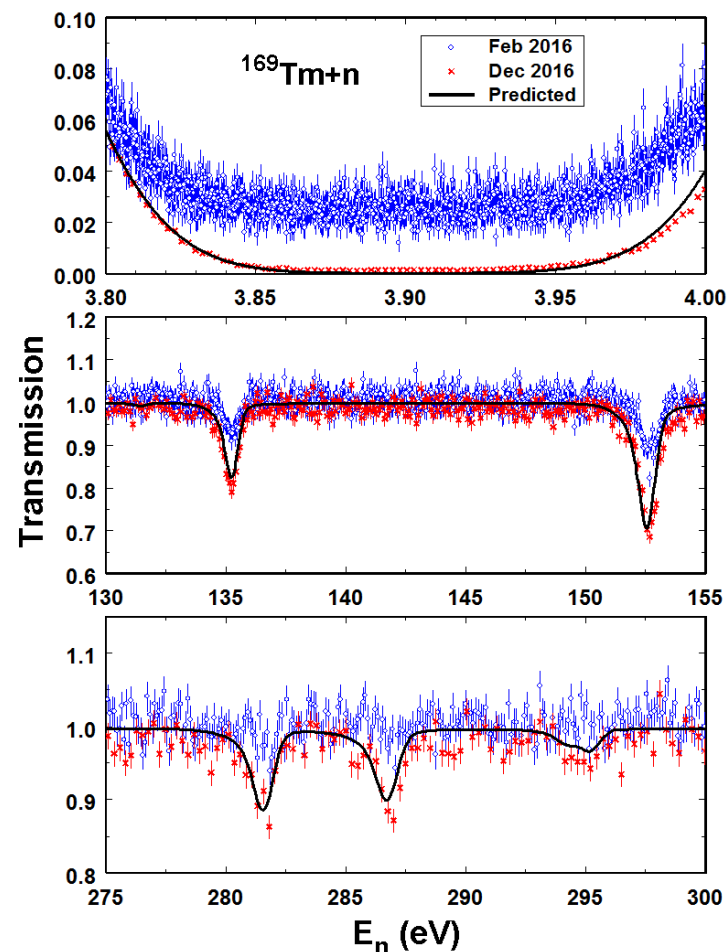


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DICER: Current Status and Future Plans

- Converting former material-science flight path
 - Removing neutron guide – largest background source
 - Replaced “cave” near detector with low-mass building
 - Installing new collimation
 - Redesigning for multiple flight path lengths
- Test measurements indicate changes made so far have greatly improved S/N
- Need to reduce sample collimator from current 6 mm diameter to <1 mm
- Exploring radioisotopes that can be produced at LANSCE IPF
 - ^{88}Y appears to be a good candidate and is of high defense-program interest
- Contact: Paul Koehler

DICER Data Before and After FP-13 Improvements

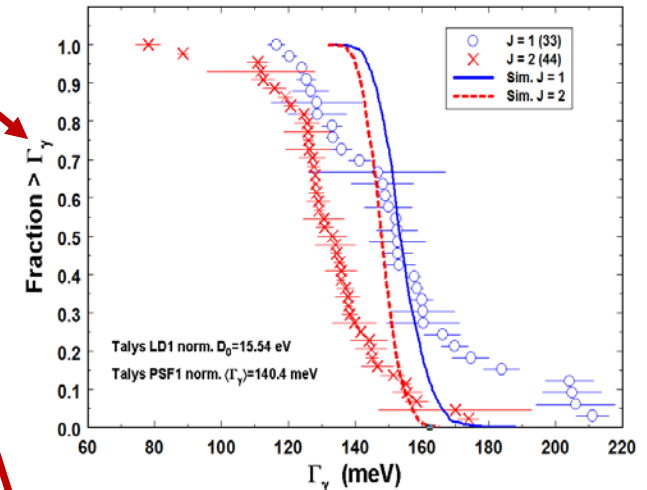


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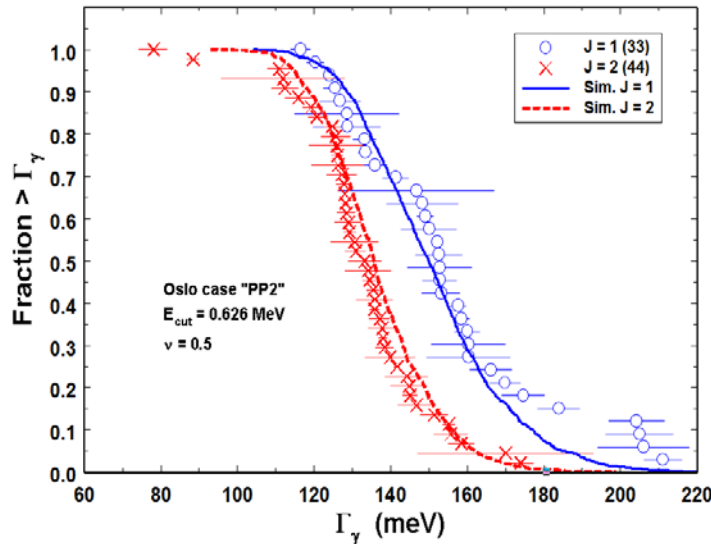
First Physics Result from DICER

- Distributions of total gamma widths (Γ_γ) for ^{197}Au neutron resonances in strong disagreement with theory
- Two substantial changes to theory can yield reasonable agreement with new DICER data
 - ^{198}Au spin distribution
 - Distribution of primary gamma widths

With TALYS default LD and PSF

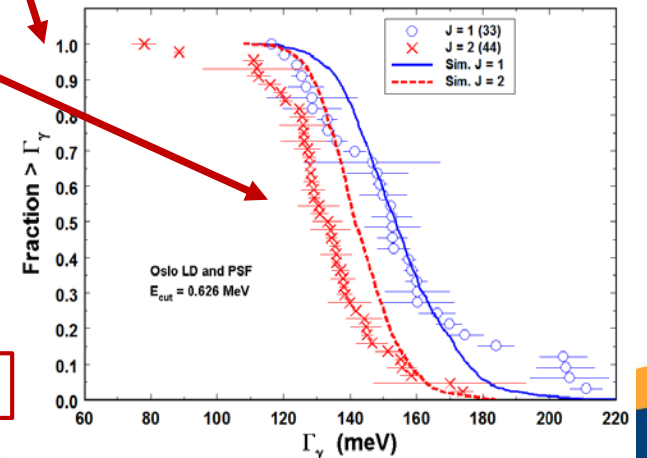


With Oslo LD and PSF and 2 Changes



Consistency
check of Oslo
Technique
Fails

With Oslo LD and PSF

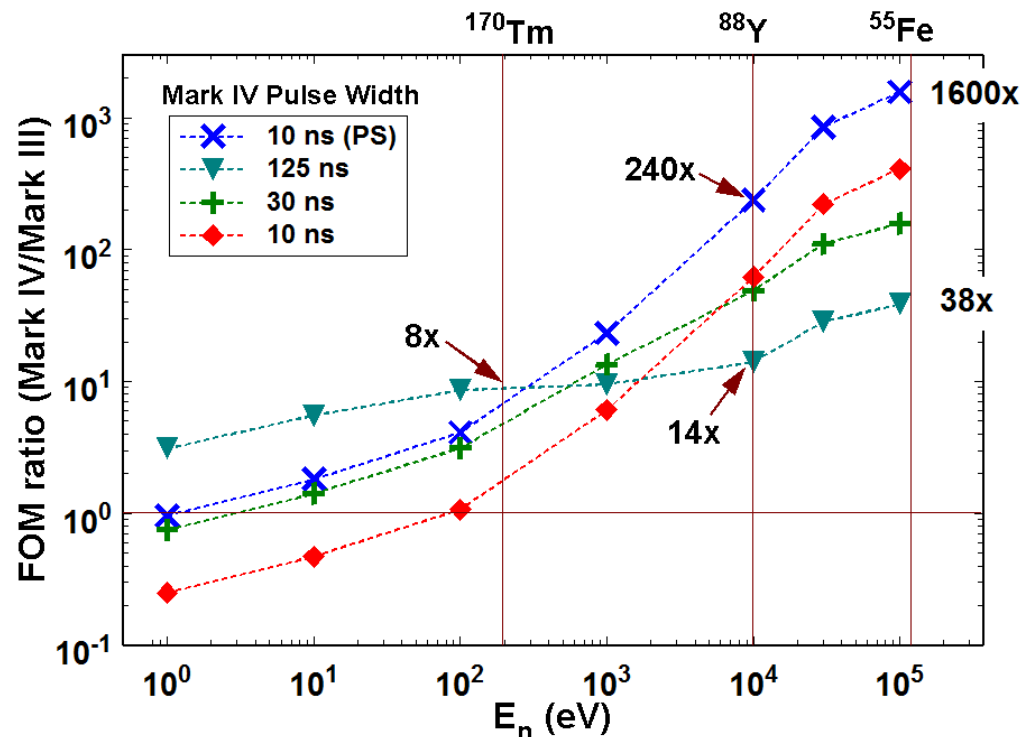
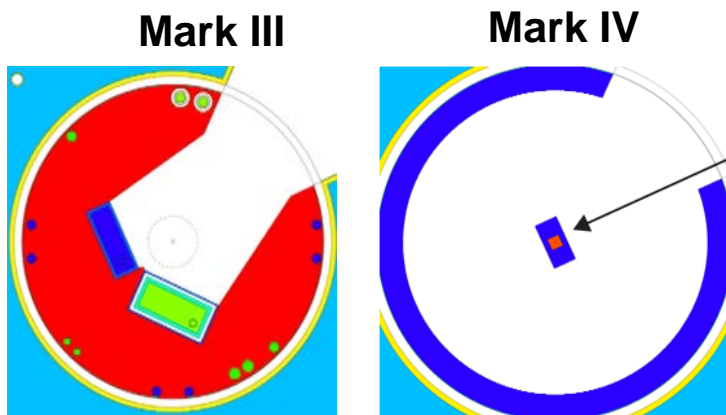


Impacts theory (n, γ) rates for nuclides beyond measurement

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New (Mark-IV) 1L Target for the Lujan Center

- Large improvement of flux and resolution for nuclear-science research
- Maintains performance for material science
- Expected installation in January 2020



$$FOM = \frac{\phi}{\Delta E^2}$$

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